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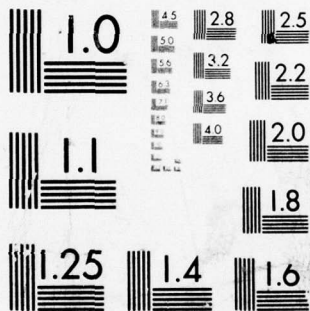
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The Surveillance Radar Detection (SURDET) model is a user-oriented computer model that produces target detections and position estimates for each radar scan. The model employs a variety of target trajectories and environments including jamming, multipath propagation, and rain and sea clutter. The model is a Monte-Carlo simulation, and the automatic detector is simulated on a pulse-to-pulse basis that takes into account target suppression and resolution effects in a dense target environment. This version documents the inclusion of an M out of N (Continues)		

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20. Abstract (Continued)

detector, a doppler processor, and monopulse capability of estimating the azimuth and elevation angles of the target.

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SURVEILLANCE RADAR DETECTION (SURDET) PROGRAM:

REVISION #1

I. INTRODUCTION

The Radar Analysis Staff of the Naval Research Laboratory has previously developed the Surveillance Radar Detection (SURDET) computer program [1]. SURDET produces radar detections and position estimates for each radar scan. These detections correspond not only to target detections but also to correlated and uncorrelated false alarms. The radar operates within a specified scenario defined by up to 20 targets and jammers in a clutter environment of rain or sea, in addition to multi-path propagation. Each target trajectory can take one of three forms: a straight line between the starting point and the endpoint, a straight line in the xy plane with different altitude legs, or a constant-altitude flight with a turn between two straight-line legs.

SURDET has been constructed as a modified time-step model. The time steps involved are determined by the elapsed time between radar scans illuminating the target. The surveillance radar under examination is characterized by its radar scan modes. A radar scan mode is a means of defining radar operating characteristics for the illumination of a specific geometrical region. Typical radar scan modes include elevation beams, long-range search, high-angle low-energy search, burnthrough, and horizon scan. At the onset of the engagement (when the earliest target leaves its initial position), the time when each operational radar scan mode will first illuminate any target is determined. The minimum time minus 30 s is compared to a maximum start time, which is an input value, and the smaller of these two times is used as the start of the simulation. The additional time before the first possible target detection is necessary for clutter generation for realistic tracking studies.

For each radar scan the signal (target), noise, jamming, and clutter energies are calculated for each target and each radar scan mode. If a target detection is possible (depending on the signal-to-interfering-power ratio), the radar return is simulated pulse to pulse in the test cell of interest and in the surrounding reference cells. This level of detail is required in order to take into account the problems of target suppression and target resolution caused by nearby

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targets. Next, target detections are declared by comparing the test cell of interest to a threshold generated from the surrounding reference cells.

Since multiple detections of a single target can occur, such detections are merged into a centroided detection. Finally, the centroided detection is corrupted by the effects of roll and pitch. The results of SURDET can be printed out and/or written onto a file for later processing by the MERIT tracking program [2].

SURDET currently exists in two versions: SURDET2D to be used with 2D radars and SURDET3D to be used with 3D radars. Although the majority of the subroutines in SURDET are common to the two versions, SURDET2D and SURDET3D each has a unique executive routine plus a small set of unique associated routines. As with most "general" computer programs, SURDET is continually being modified and updated. This report is concerned with two basic changes to SURDET3D. First, the choice of automatic detectors has been expanded by including an M out of N detector and a doppler processor. Secondly, monopulse has been added to increase SURDET3D's capability of obtaining more accurate angle estimates. The second section describes the changes and the third section describes the new input for SURDET3D. It should also be noted that several minor changes have been made: a) the output from SURDET3D has been modified slightly, b) the rain clutter calculation has been changed, c) the elevation beam location is now specified by its maximum gain position rather than its lower 3-dB point, and d) the reinitialization of the random number generator for the clutter point routines has been changed.

II. MODEL CHANGES

This section briefly describes three changes to SURDET3D. These changes are the inclusion of an M out of N detector, a doppler processor, and a monopulse processor.

A. M OUT OF N DETECTOR

The M out of N detector is also called in the literature a dual threshold detector or a binary integrator. The detector first quantizes a single pulse to either a 0 or 1 by comparing it to a threshold which is generated from the surrounding reference cells. Then, if there are M 1's in the N pulses, a target is declared.

This detector is implemented in DET3D by repeating the following calculations for each i-th pulse of the N pulses on target. First, let

$$N_j = 0 \quad (1)$$

and

$$Z_j = x_{ij} \quad i = 1, \dots, N \quad (2)$$

where x_{ij} is the i -th pulse in the j -th range cell. Then, the appropriate threshold T_j (for the i -th pulse) is calculated using equations (123) to (128) in [1]. Next Z_j is compared to T_j . If $Z_j \geq T_j$, the counter N_j is incremented by 1. If $N_j \geq M$ after all N pulses are processed, a target is declared.

B. DOPPLER PROCESSOR

The doppler processor is a device for performing coherent integration on a signal containing an unknown doppler frequency. First, the Fourier transform of N pulses is calculated, generating N doppler signals. Each doppler signal is compared to a threshold which is calculated using the corresponding doppler signals in the surrounding reference cells. If for any range cell and beam position more than one doppler signal exceeds the detection threshold, only the detection corresponding to the largest signal is reported.

This detector is implemented in DET3D by first calculating the Fourier transform of the complex received samples x_{ij} , i.e.

$$d_{\ell j} = \sum_{i=1}^N x_{ij} \exp \{ \sqrt{-1} \, 2\pi (i-1) (\ell-1) / N \} \quad (3)$$

Then, the following calculations are performed for each ℓ -th doppler bin:

$$N_j = 0 \quad (4)$$

$$Z_j = |d_{\ell j}| \quad \ell = 1, \dots, N \quad (5)$$

Then, again the appropriate threshold T_j (for the ℓ -th doppler bin) is calculated using equations (123) to (128) in [1]. Next Z_j is compared to T_j . If $Z_j \geq T_j$, the counter N_j is incremented by 1. If $N_j \geq 1$

after all N pulses are processed, a target is declared and its estimated parameters correspond to the doppler bin with the highest amplitude.

C. MONOPULSE PROCESSOR

The type of monopulse implemented is a phase monopulse and it can be used with any of the three different detectors. However, for the noncoherent integrator, it can only be used if no integration is being performed. For the M out of N integrator, the monopulse calculation is performed on the M-th pulse which crosses the detection threshold. For the doppler processor, monopulse requires a Fourier transform of the difference channels and this calculation is performed in DET3D.

The monopulse calculations are performed in BEAM, DET3D, GAIN, and MULPTH. First, the complex received signals can be represented by

$$x_{ij}(S) = S [G_{SA}(\theta_a - A) G_{SE}(\theta_e - E) + G_{SA}(\theta_a - A) G_{SE}(\theta_e + E) \rho e^{i\theta}] \quad (6)$$

$$x_{ij}(ED) = S [G_{SA}(\theta_a - A) G_{DE}(\theta_e - E) + G_{SA}(\theta_a + A) G_{DE}(\theta_e + E) \rho e^{i\theta}] \quad (7)$$

$$x_{ij}(AD) = S [G_{DA}(\theta_a - A) G_{SE}(\theta_e - E) + G_{DA}(\theta_a - A) G_{SE}(\theta_e + E) \rho e^{i\theta}] \quad (8)$$

where $x_{ij}(S)$ is sum signal, $x_{ij}(ED)$ is the elevation difference signal, $x_{ij}(AD)$ is the azimuth difference signal, $G_{SA}(\cdot)$, $G_{SE}(\cdot)$, $G_{DA}(\cdot)$, and $G_{DE}(\cdot)$ are the sum azimuth and elevation and difference azimuth and elevation antenna gains respectively, θ_a is the azimuth pointing angle of the beam, θ_e is the elevation pointing angle of the beam, A is the target azimuth, E is the target elevation, ρ is the multipath reflection coefficient, ϕ is the phase difference between the direct and reflected signal paths, and the factor S contains the result of all other common factors in the radar range equation. The antenna gains are given by

$$G_{SA}(\theta) = \frac{\sin(\theta_1)}{\theta_1} \quad (9)$$

$$G_{DA}(\theta) = \frac{1 - \cos(\theta_1)}{\theta_1} \quad (10)$$

where $\theta = 2.7832\theta/\theta_{A3DB}$, θ_{A3DB} being the azimuth 3 dB antenna beamwidth and

$$G_{SE}(\theta) = \frac{\sin(\theta_2)}{\theta_2} \quad (11)$$

$$G_{DE}(\theta) = \frac{1 - \cos(\theta_2)}{\theta_2} \quad (12)$$

where $\theta_2 = 2.7832\theta/\theta_{E3DB}$, θ_{E3DB} being the elevation 3 dB antenna beamwidth. The monopulse estimates are given by

$$\hat{A} = \theta_a - \frac{\theta_{A3DB}}{1.3916} \tan^{-1} \left\{ \frac{x_{ij}^*(S) x_{ij}(AD)}{x_{ij}^*(S) x_{ij}(S)} \right\} \quad (13)$$

and

$$\hat{E} = \theta_e - \frac{\theta_{E3DB}}{1.3916} \tan^{-1} \left\{ \frac{x_{ij}^*(S) x_{ij}(ED)}{x_{ij}^*(S) x_{ij}(S)} \right\} \quad (14)$$

where * indicates complex conjugate and signals given by (6), (7), and (8) have been corrupted by noise generated in the manner indicated in [1].

A strong target will be detected in several range cells and beam positions. To merge these detections into a single centroided detection subroutine ADJDET is called to determine whether the i-th detection of target KTAR in the j-th mode is adjacent to any detection k in the set of K detections which have previously been determined to be adjacent.

For monopulse a detection is added to the previous set of K adjacent detections if

$$|R - R_k| \leq 1.2 \Delta R \quad (15)$$

$$|A - A_k| \leq 0.5 \theta_{Z3DB} \quad (16)$$

and

$$|E - E_k| \leq 1.0 \theta_{E3DB} \quad (17)$$

where R, A, and E are the range, azimuth, and elevation of the detection being tested, R_k , A_k , and E_k are the range, azimuth, and elevation of the k-th detection in the set of adjacent detections, and ΔR is the range resolution.

III. INPUT FOR SURDET3D

An engagement scenario consists of a radar, one or more targets to be detected, and an optional number of sources of jamming radiation (subsequently referred to as jammers) set in a specified environment. The number of targets and jammers together is limited to 20. The required input information is divided into the definitions of the radar, targets, and jammers, an environment with optional clutter, and output and recycle control parameters. Most of the data cards are the same as those in [1]. However, the following changes have been made: a) Data Card 4 - parameters 12 and 13 have been added; b) Data Card 5 - parameter 1 has been changed; c) Data Card 6 - parameter 6 has been added; and d) Data Card 7 - this card is now required for each scan mode and parameters 4 through 8 have been changed. For completeness, the entire input structure is now described:

Date card 1 - printed-out control integer (I5 format):

- 0 = no output printed,
- 1 = only the detection output printed,
- 2 = detailed output printed;

Data card 2 - title card (I4,19A4 format):

- 1. Radar integer ID,
- 2. Alphanumeric run identification;

Data card 3 - ship (radar) position (4F8.2 format):

- 1-3. Position coordinate (x,y,z) (kft),
4. Ship heading (deg);

Data card 4 - 13 basic radar parameters (9F6.2,I6,3F6.2 format):

1. Radar frequency (MHz),
2. Antenna pattern function indicator (0 = pencil beam and 1 = cosecant-squared beam),
3. Receiver noise (dB),
4. Horizontal 3-dB beamwidth (deg),
5. Vertical 3-dB beamwidth (deg),
6. One-way antenna gain (dB),
7. One-way sidelobe level (dB down from peak),
8. Receiver loss (dB),
9. Transmitter loss (dB),
10. Number of scan modes (limited to 30),
11. Linear polarization (0° to 90°, where 0° = horizontal and 90° = vertical);
12. Azimuth offset between beam positions
13. Indicator of monopulse processing (1 = monopulse; otherwise no monopulse)

Data cards 5,6, and 7 (one set for each radar scan mode) - 24 parameters for each scan mode (10F8.2/6F8.2/6F8.2,2I8 format):

Data card 5

1. Center of elevation beam (deg),
2. Upper 3-dB point of the elevation-angle coverage (deg),
3. Peak power (MW),
4. Pulse length (μ s),
5. Interlook period(s) (must be identical for all modes),
6. Scan offset (s),
7. Instrumented range (n.mi.),
8. Mode-dependent loss (dB),
9. Number of pulses integrated,
10. Compressed-pulse length (μ s),

Data card 6

1. Sea-clutter improvement factor (dB),
2. Intermediate-frequency bandwidth (MHz) (if 0, the bandwidth is set at 1.0/compressed-pulse length),
3. Mode-dependent frequency increment (MHz),
4. Blanking time (μ s) (if 0, the blanking time is set at the pulse length),
5. Rain-clutter improvement factor (dB);
6. Pulse repetition rate (pps)

Data card 7

1. Number of reference cells on each side of the target cell,
2. Clutter correlation coefficient,
3. Number of standard deviations used in the threshold which determines the probability of false alarm (guidance in setting the threshold value is given by Appendix A of [1],
4. Video-type indicator (0=linear video and 1=log video),
5. Number of reference cells used for the threshold (0=all cells used, < 0 = half with smaller mean value used, and > 0 = half with larger mean value used),
6. Parameters used to calculate the threshold (1=mean used and 2 = mean and variance used);
7. Indicator of detector type (1 = noncoherent integration, 2 = M out of N detector, or 3 = doppler processor,
8. M in M out of N detector,

Data card 8 - number of targets and jammers (total limited to 20) (2I5 format):

1. Number of targets,
2. Number of jammers;

Data card 9 (one card for each target and jammer, paired with a card 10) - 13 target parameters (12F6.2,I3 format):

- 1-4. Initial coordinates (x,y,z) (kft) and time (s),
- 5-8. Terminal coordinates (x,y,z) (kft) and time (s),
- 9-11. Head-on, broadside, and minimum radar reflective areas (m^2),
12. Jamming power density (W/MHz),
13. Marcum-Swerling cross-section model number;

Data card 10 (one card for each target and jammer, paired with a card 9) - target profile parameters (I4,7F6.2 format):

1. Target profile type (0= straight-line trajectory, 1 = altitude legs, and 2 = g maneuver at constant altitude), with profile parameters 2 through 8 that follow being ignored for target profile type 0 and being as indicated for target types 1 and 2,
2. Number of altitude nodes (maximum of three), for target type 1, or target speed (kft/s), for target type 2,
3. First altitude node (kft), for target type 1, or initial heading of the target (deg), for target type 2,
4. Time of the target arrival at the first node (s) for target type 1, or time the maneuver begins, for target type 2,
5. Second altitude node (kft), for target type 1, or radial acceleration of the maneuver (g's), for target type 2,
6. Time of the target arrival at the second node (s), for target type 1, or ignored for target type 2,

7. Third altitude node (kft), for target type 1, or ignored for target type 2,
8. Time of the target arrival at the third node(s), for target type 1, or ignored for target type 2;

Data card 11 - four environmental parameters (4F8,2 format):

1. Wind speed (knots),
2. Height of the wind-speed measurement (kft),
3. Multipath indicator (1 = multipath and 0 = no multipath),
4. Rainfall rate (mm/h);

Data card 12 - nine fixed clutter parameters (2I8,7F8.2 format):

1. Initialization for the random-number generator for generation of fixed clutter points,
2. Number of fixed clutter points,
3. Probability that a clutter point is detected,
4. Initial range of the clutter area (kft),
5. Final range of the clutter area (kft),
6. Standard deviation of the range measurement (percent of the range-resolution cell size),
7. Initial azimuth of the clutter area (deg),
8. Final azimuth of the clutter area (deg),
9. Standard deviation of the azimuth measurement (percent of the horizontal 3-dB beamwidth);

Data card 13 - two basic variable clutter parameters (2I8 format):

1. Initialization for the random-number generator for generation of variable clutter points,
2. Number of clutter regions;

Data card 14 - (one card for each clutter region) - seven parameters for each clutter region (7F8.2 format):

1. Average number of clutter points in the region,
2. Initial range of the clutter area (kft),
3. Final range of the clutter area (kft),
4. Initial azimuth of the clutter area (deg),
5. Final azimuth of the clutter area in (deg),
6. Initial elevation of the clutter area (deg),
7. Final elevation of the clutter area (deg),

Data card 15 - four roll and pitch parameters (4F8.2 format):

1. Maximum roll angle (deg),
2. Maximum pitch angle (deg),
3. Roll period (s) (a number >0 should be specified),
4. Pitch period (s) (a number >0 should be specified);

Data card 16 - time parameter (F8.2 format):

1. Game time (s) by which the radar must initiate scanning;

Data card 17 - recycle control parameter (I5 format):

- 1 = a new scenario is to be read, with the next data card being data card 1,
- 2 = current radar parameters are to be retained, but new targets and environment are to be read, with the next data card being data card 8,
- 3 = current radar and target parameters are to be retained, but a new environment is to be read, with the next data card being data card 11,
- 4 = all runs completed.

All input data from data cards 2 through 16 are printed as output at the beginning of each run.

IV. SUMMARY

This report has documented the inclusion of an M out of N detector, a doppler processor, and a monopulse capability to SURDET3D. In addition, the new input structure is given. Also various minor changes have been made, which resulted in the following routines being modified: ADJDET, BEAM, DET3D, FORXFM, FXCLT3, GAIN, INITAL, INIT3D, JAM, MRDT3D, MULPTH, NEWPOS, SIGNAL, SURDET, and VRCLT3. Since the new version of SURDET3D can perform all the functions of the old SURDET3D, it can replace the old version.

V. REFERENCES

- [1] Laura C. Davis and Gerard V. Trunk, "Surveillance Radar Detection (SURDET) Program," NRL Report 8228, August 11, 1978.
- [2] J.D. Wilson, "A Multiple-Radar Integrated Tracking (MERIT) Program," NRL Report 8200, April 3, 1978.